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Advanced radiographic techniques for the detection of lesions in bone

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Radiographs in endodontics are of importance for the study and management of periapical lesions. With the development of advanced systems in traditional radiology, new and more accurate imaging techniques are constantly under investigation. Computerized tomography, magnetic resonance and real-time echotomography have been introduced in recent years to the field of endodontics: they may have advantages over conventional techniques for the amount of detailed information they can provide on specific cases. This paper reviews these new imaging techniques with respect to their possible role in the diagnosis and management of periapical lesions.

Conventional radiographs traditionally form the backbone in the diagnosis, treatment procedures and follow-up of endodontic cases (Fig. 1a–c).

One of the most important roles played by imaging in clinical endodontics is the possibility of diagnosing and describing lesions in the jaw bones that originate from infection of the root canal (Fig. 2a–c).

Most of the osteolytic lesions in the jaws are in fact related to chronic apical periodontitis. The so-called 'bony lesions of endodontic origin' are a common finding in dental radiology and are generated by the pathologic changes occurring in the periradicular tissues as a consequence of pulpal infection and necrosis. Periradicular tissues surround and interact with the root of the tooth. They originate from the dental follicle, which surrounds the enamel organ, and this 'unit' consists of the cementum, of the periodontal ligament (with its bundles of collagen fibres, extensive network of vessels and nerves) and of the alveolar bone.

The interaction between the irritants exiting the root canal to the periradicular tissues and the host defence results in the activation of both non-specific inflammatory reactions and specific immune reactions.

As the disease proceeds, soft tissues produced by the inflammatory reaction substitute the periapical bone. Besides the possible clinical signs and symptoms associated with the different stages of this condition (such as swelling-sinus tracts- pain to percussion of the tooth and palpation of the area) there are changes in the mineralization and structure of the bone that can be visualized by radiographic techniques (1–3). Periapical lesions of endodontic origin in the maxillary and mandibular bone may be distinguished into cysts and granulomas depending on their nature and histopathological features. Making a differential diagnosis between a cyst and a granuloma may have some importance in the management of the lesions, with special regard to the predictability of endodontic treatment success and the possible explanation of failure (2, 4, 5).

In order to investigate and screen pathologic conditions of the jaws, especially if they originate from an endodontic infection, conventional imaging techniques may be obtained with traditional radiology by means of intraoral periapical, occlusal and panoramic radiographs. Furthermore, digital radiography has, in the last 10 years, become extremely valuable as an alternative to conventional radiology with a significant reduction (50–80%) in radiation exposure and with possibilities of color-enhancing systems and densitometric and subtraction methods (6).

But conventional radiographs have limitations that have stimulated an extensive search for improvement.

Radiographs are the two-dimensional projection of three-dimensional (3D) structures; most of the times they are not sufficient to provide information on the

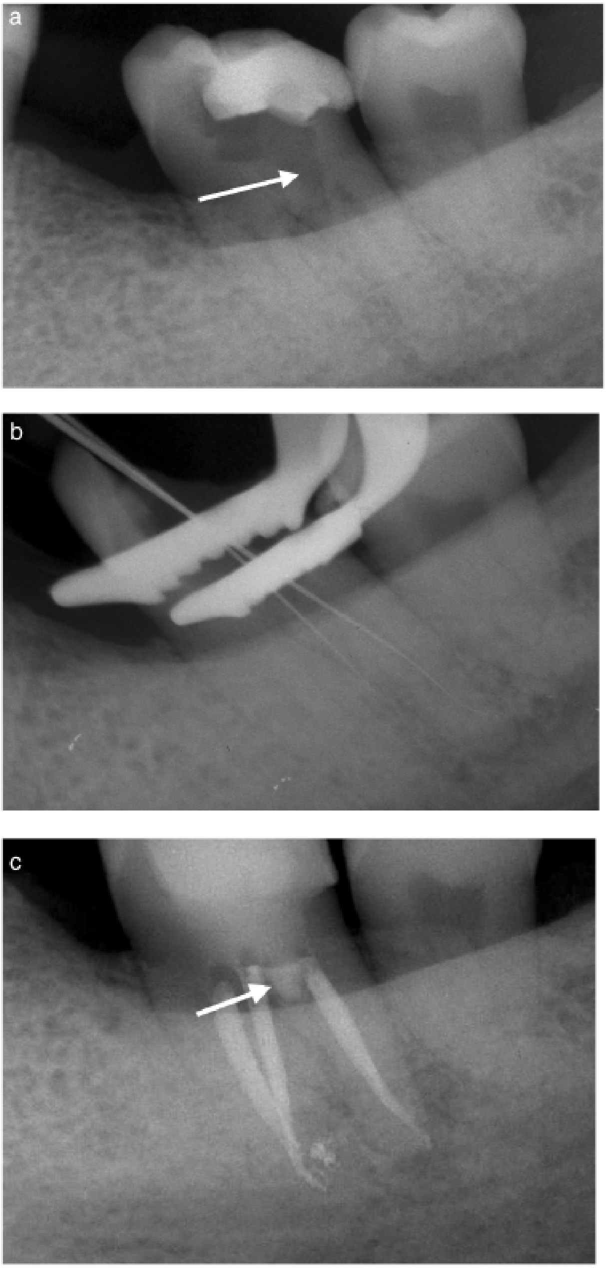


Fig. 1. Importance of periapical radiographs during endodontic treatment. (a) Lower left second molar; perforation of the floor of the pulp chamber (arrow). (b) Identification of the perforation site and of the distal canal (c) Root canal treatment has been completed and the perforation has been repaired (arrow).

actual size of the lesions (7, 8), their spatial relationship with anatomic landmarks (9), and it has been proposed that the amount of bone that has to be resorbed before a lesion becomes clearly visible is quite extensive (9). Radiographs are limited to visualization of hard tissues and not of soft tissues; therefore, they cannot guide the clinician towards a diagnosis of the soft tissue characteristics of the lesions (5).

Furthermore, they require careful interpretation and are prone to observer bias (6, 10).

Supporting these traditional imaging methods, partly overcoming some of the limitations of the techniques, and sometimes gaining more specific information that can be used either for diagnostic purposes or for investigation protocols, more advanced diagnostic systems have been applied to endodontic situations in the past 10–15 years, namely, computerized tomography (CT), nuclear magnetic resonance and ultrasound real-time echotomography.

CT

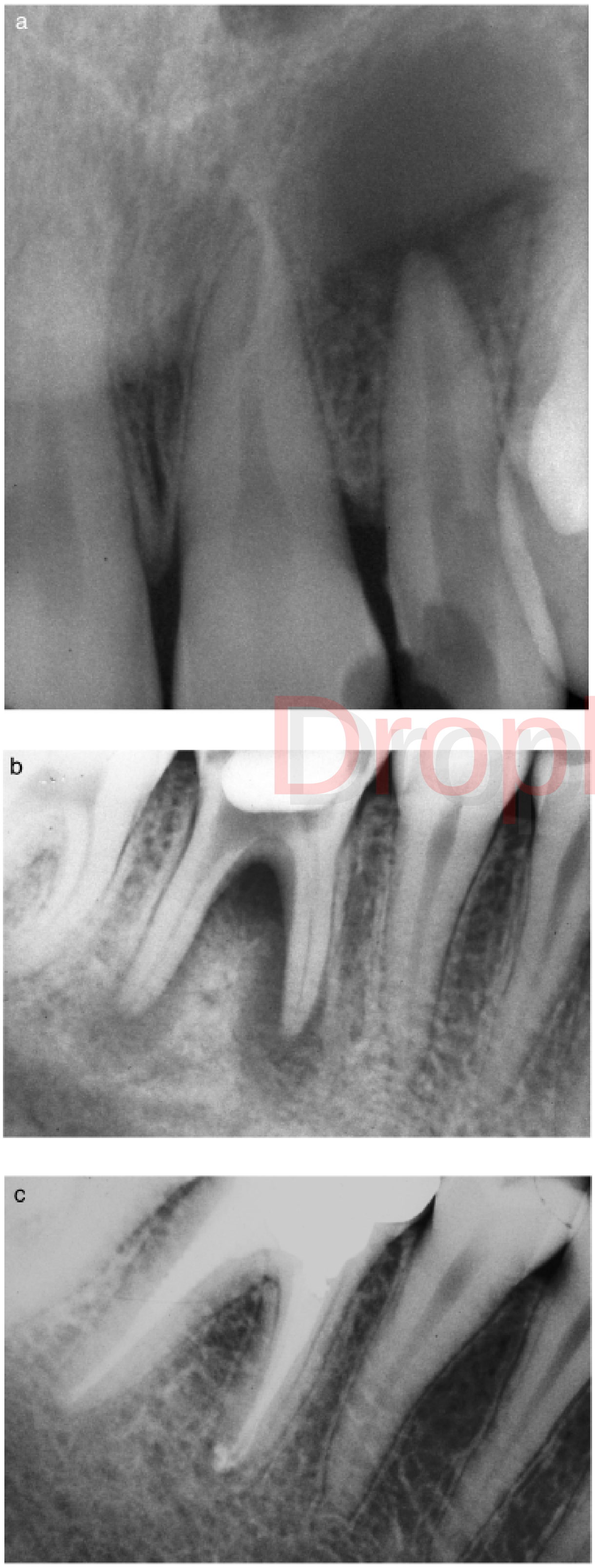
Hannsfield (11) devised the computerized axial tomography during the 1970s.

CT is an X-ray imaging technique that produces 3D images of an object by using a series of two-dimensional (2D) set of image data to mathematically reconstruct a cross-section of it. This system measures the attenuation of X-rays entering the body from many different angles. The computer then reconstructs the part under observation in a series of cross sections or planes.

CT is unique in that it provides imaging of a combination of soft tissues, bone and vessels, and the technique has become a widely used method for the diagnosis of pathologic conditions in the maxillary bones and plays a major role when used following a preliminary screening with a panoramic or a periapical radiograph. Many studies have confirmed CT to be a valid complement to conventional imaging methods (12). Historically, before dental CT was introduced to study the anatomy and pathology of the jaw bones, conventional orthoradial tomography associated with a complex blurring device (Scanora, Soredex, Helsinki, Finland) was applied to dental and oral tissues.

Conventional orthoradial radiography is still in use today, but it takes a longer time in order to allow imaging of the complete jaw and it is less accurate and more prone to errors (13). A study by Tammisalo et al. (14) demonstrated that in the overall diagnosis of periapical and periodontal lesions the Scanora system and periapical radiographs performed equally well, tomograms being more detailed only for detecting periapical lesions in posterior regions. There are several

techniques related to CT in the dental field: dental CT, ortho CT, local CT, tomosynthesis and tuned aperture computed tomography (TACT), and micro-CT.



Dental CT

Dental CT was introduced in 1987 and it is defined as a technique, which uses a specific protocol of investigation (15, 16). In dental CT, axial scans of the jaws are acquired using the highest possible resolution, and curved as well as orthoradial multiplanar reconstructions are obtained.

The coronal plane is not generally used for the scans in dental CT, since the metal artefacts from teeth fillings and other metal-dental work are frequent and appear in these sections. Using the axial planes, the occlusion plane will still have the artefact displayed, but the bone will be left undistorted.

Dental CT can be performed with a conventional CT, a spiral CT or a multislice CT scanner. The device should give high-resolution scans with a small focal spot and the acquired slices should be of 1.5 mm thickness or less.

The slower the rotation of the tube, the more detailed is the information gained. In order to achieve routine images of the jaws, a spiral scan technique of 1 s per rotation is valid; if small details need to be obtained for diagnostic purposes, then 2 s per rotation need to be used. The standard protocol for dental CT in the diagnosis of pathologic conditions is as follows: Incremental scan type; 1.5 mm slice thickness; 1.0 table feed; 120 mm field of view (for the mandible); 100 mm field of view (for the maxilla); 2 s scan time; 512 matrix; 12 kV; 25–100 m A; high-resolution edge enhanced filter, 2000+400 HU (Hounsfields units) bone window; mandible base and hard palate as scan planes (17).

After the examination is completed, the axial slices are transferred to a workstation to perform multiplanar reconstructions; this is accomplished through dental software.

The multiple orthoradial reconstructions are calculated perpendicular to a planning line that is manually drawn along the centerline of the jaw arch. The distance between each of the 40–60 cuts is of 1.5–3.0 mm (Fig. 3). Panoramic reconstructions are calculated along the

Fig. 2. Lesions of endodontic origin in the jaws as shown in periapical radiographs. (a) Upper left lateral incisor; deep caries and periradicular lesion. (b) Lower right first molar; deep caries and periradicular lesion. (c) Radiograph showing 1-year follow-up of the same tooth: healing of the lesion is evident and the bone pattern has been re-established.

Fig. 3. Dental computerized tomography examination of the maxilla in a case of extensive periapical lesion. Reconstructions are performed from axial slices.

planning line. For a single jaw scan, all images can be displayed on three hard copies for an overview of the complete investigation: the first two showing the axial scans. The third copy displays the dental reconstructions in a 1 : 1 scale, it includes also the planning line and the orthoradial lines, plus the subsequent scans, which are numbered, thus allowing a correlation with the orthoradial reconstructions.

Panoramic reconstructions are shown in the same copy and allow correlation with the orthoradial reconstructions by indicating their position (Fig. 4a–c).

A major concern related to dental CT is the high radiation dose required for average exams; in the last years dose reduction methods have therefore been established (18).

Reducing the tube current is an important step for dose reduction. This is followed by using a 1.5 mm slice thickness instead of 1.0 mm, or using a spiral technique with a pitch factor of more than 1.0. An additional and important means of dose reduction is to limit the area of interest for the investigation by selecting the upper or lower jaw and excluding all the occlusal scans (which are mostly useless and subject to artefacts from metallic objects) (17, 18).

Spiral CT scanners use continuous scanning to generate cross-sectional slices and make a set of 3D images. In this way the time it takes to produce tomographic pictures is reduced.

Results from the application of dental CT in endodontics

In normal and pathologic conditions the tissues of the jaws that are visualized in dental CT are the alveolar processes with the teeth, the base of the mandible with its vessels and canals, the maxillary sinus; the floor of the nose and the incisal canal.

The alveolar process is the portion of the mandibular bone and of the maxillary bone that holds the roots of the teeth, the periodontal ligament, the periapical tissues and the lamina dura. The alveolar process is therefore the area of major interest in the field of endodontics: it is the area where most pathologic changes occur involving the condition of the roots of the teeth, the possible presence of foreign bodies, and osteolytic or condensing inflammatory reactions in the bone. The alveolar process is easily visualized in dental CT, both in axial slices and in orthoradial reconstructions. The root of the teeth can be visualized; the periodontal space can be discerned especially if there are pathologic conditions. The mandibular canal is an important feature of the imaging obtained scanning the base of the mandible; if it is well surrounded by cortical bone it is clearly visible both on axial scans and on reconstructions. If the cortical bone is interrupted, then the canal may be obscured from the surrounding cancellous bone, but its position can be easily extrapolated by the reconstructions of slices where the canal is visible.

The extension of the maxillary sinus and the floor of the nose and their relationship with the roots of the teeth are of great importance in the study of the origin and dimension of endodontic lesions; dental CT will offer a very good imaging of these structures (Fig. 3) (17, 19).

Chronic apical periodontitis can also be seen with the CT scan: when a lesion is at an early stage, or when the slice covers the smallest portion of a well-established one, it is seen as an enlargement of the periodontal space, this can also be clearly seen as a small osteolytic reaction around the root's tip (Fig. 4a–c).

A reactive enlargement of the trabecular bone follows this enlargement of the periodontal space. Further expansion of the pathologic reaction in the cancellous and cortical bone may easily be seen both on axial scans and on the reconstructions, including a detailed visualization of the involvement or erosion of the cortical plates (9, 17).

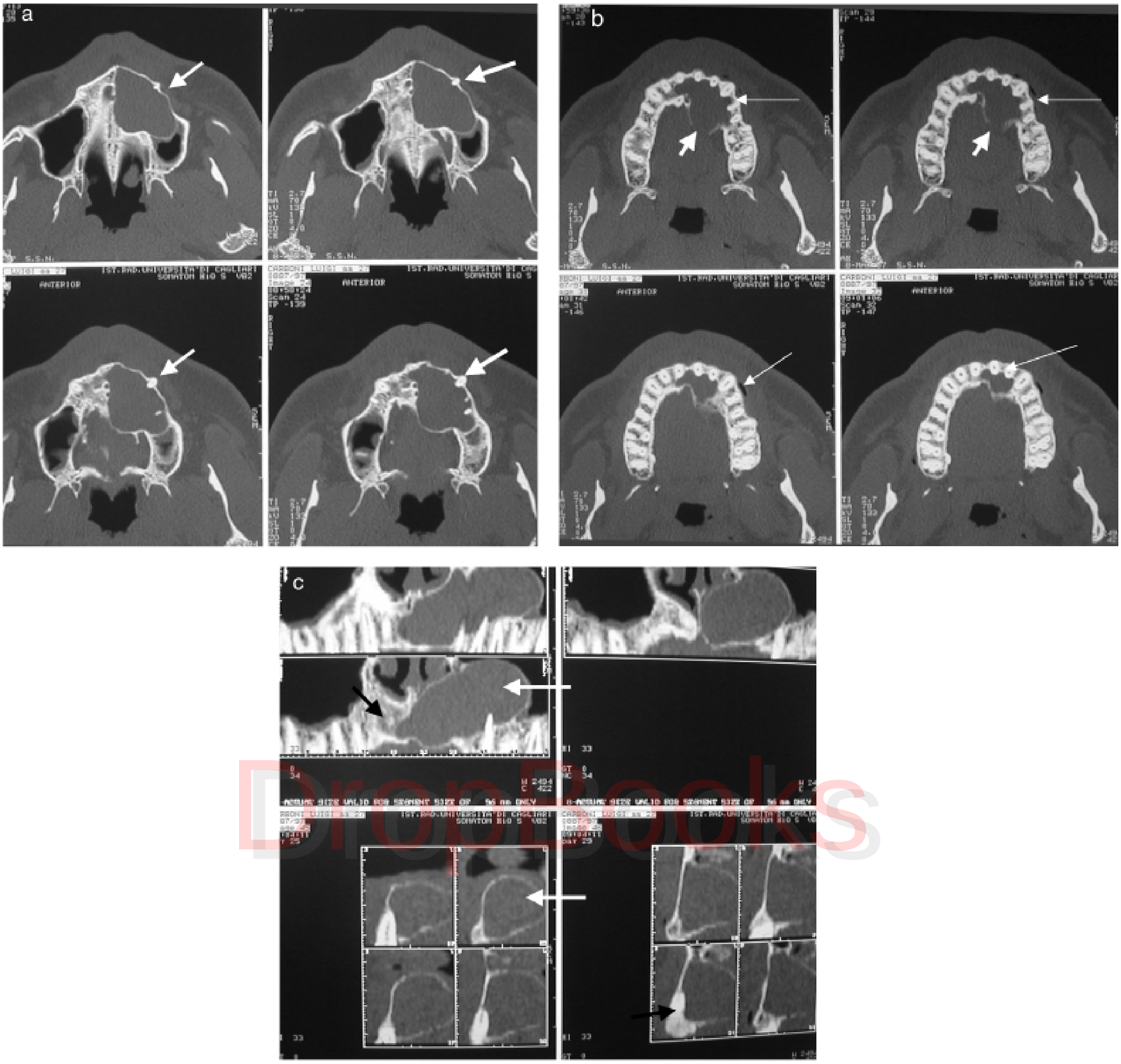


Fig. 4. Dental computerized tomography examination of the maxilla in a case of extensive periapical lesion. (a) Axial slices of the maxilla showing an extensive periapical lesion of endodontic origin. There is a significant amount of bone destruction and the root of the tooth is visible in all the slices (arrows). (b) Lower axial slices of the same case. The roots of the teeth of the maxilla are visible, with their periradicular bone (long arrows). In the upper slices the lingual cortical plate shows signs of erosion and displacement (short arrows). (c) Panoramic and orthoradial reconstructions of the same lesions showing the alveolar crest (black arrows) and the maxillary sinus (white arrows).

While vertical root fractures or split teeth can seldom be seen by means of a normal periapical radiograph, they may be more easily detected in CT scans. Limitations are related to small fractures that are below the resolution power of the CT, or to the superimposition of metal restorations (20). CT may also be applied for localizing the presence of foreign bodies in the jaws (17).

Trope et al. (21) pioneered the application of CT to endodontic imaging. They evaluated eight periapical lesions on human cadavers with a CT scan, axial slices and a densitometric processor. The computerized examination of the lesions was correlated to the histopathology. They concluded that cystic cavities could be differentiated form granulomas based on their appearance in the tomographs. They observed that a cyst would appear as an area markedly darker when compared to a granuloma or to the fibrous tissue of an apical scar. The cystic area would have a density reading

similar to the background, while the granuloma would show a cloudy appearance with a density similar to the one exhibited from the surrounding soft tissues.

Marmary et al. (9) used a high resolution dental CT (object size = 0.25–0.3 mm) to examine 42 periapical lesions that had been diagnosed using conventional periapical radiographs. By performing axial slices and using reconstruction software, they obtained a series of cross sections of the jaws. Periapical lesions would occupy an average of 3–4 mm sections one of which would demonstrate the widest bucco-lingual dimension of the lesion. With this system, they found that the margin of the cortex and the periphery of the lesion could be easily identified in cross-sectional reconstructions. They demonstrated that 74% of the lesions observed were in fact confined to the cancellous bone without any kind of erosion or involvement of the cortical plates. Using this sophisticated examination, they also observed that the erosion of the cortical plate in cases of periapical lesions might be largely a consequence of the spatial relationship of the cortices to the apices of the teeth involved.

After several years of experience with applications of CT examinations in the dental clinics at the University of Cagliari, we have found the large amount of detailed information that can be gained in cases of extensive periapical lesions of endodontic origin to be very useful (Fig. 5). The information is especially important when a complex surgical procedure has to be planned and when there are doubts concerning the lack of healing of apparently correctly treated cases. E.g., particular in one case that we reported (22) a wide lesions of the maxillary bone was examined and followed-up using both CT scan and panoramic radiograph. Here the real extension of the lesion, the erosion of the floor of the nose and of the mesial wall of the naso-palatine canal could only be seen in detail using axial slices of the CT. Concerning follow-ups, the panoramic radiograph at 18 months recall disclosed the appearance of a lesion that would have been considered healed for about 70% of its extension when compared with the starting radiograph, however, the CT demonstrated that this apparent healing was seen because the external cortical plate, which was previously eroded, had been regenerated; but the size of the lesion had not decreased anywhere near the extent that was inferred from the panoramic radiograph (Fig. 6a–d).

From a case like that, one may speculate that the healing process of a large bone lesion starts with the reconstruction of the external cortical plate and is followed much later by the formation of cancellous bone and the repair, in this case, of the floor of the nose. In another case followed by CT, a persistent lesion in the periapical region of a right maxillary canine with a wide apex, besides giving information on the overall characteristics of the lesion, the CT showed the presence of a foreign particle that recalled the aspect of dental tissues. During the surgical procedure, the foreign body was removed from the area and after examination it appeared as piece of the root that was probably displaced after a traumatic injury and had since acted as an irritant (Fig. 7a–d).

Another case displayed a dense bone reaction in the periradicular space of an endodontically treated right mandibular molar (Fig. 8a, b).

Velvart et al. studied *in vivo* 50 mandibular posterior teeth affected by periapical pathosis and scheduled for endodontic surgery. They compared the information obtained on the use of high resolution CT scan with those gained from conventional periapical dental radiographs. The information was then correlated to clinical findings during surgery. They found that all the information achieved by means of the tomographs were more detailed regarding the presence, characteristics and location of the lesions, and provided important imaging concerning the relation of the lesions to the mandibular canal. They therefore concluded that CT should be seriously considered before endodontic surgery (23).

Dental CT in the differential diagnosis of periapical lesions and other pathologic conditions of the jaws

There are few lesions in the jaws that may present difficulties in the differential diagnosis with apical periodontitis because they are relatively well-circumscribed radiolucent lesions (24). The most common are the non-endodontic odontogenic cysts such as the lateral periodontal cysts, the odontogenic keratocysts, and the dentigerous cyst. Among the other lesions are the non-odontogenic developmental cysts, the traumatic bone cysts and some forms of ameloblastoma. Cemental dysplasia is the most common sclerotic lesions of the jaws. CT has been used with success to help in the differential diagnosis of these lesions.

The odontogenic keratocysts is a developmental lesion derived from the remnants of the dental lamina.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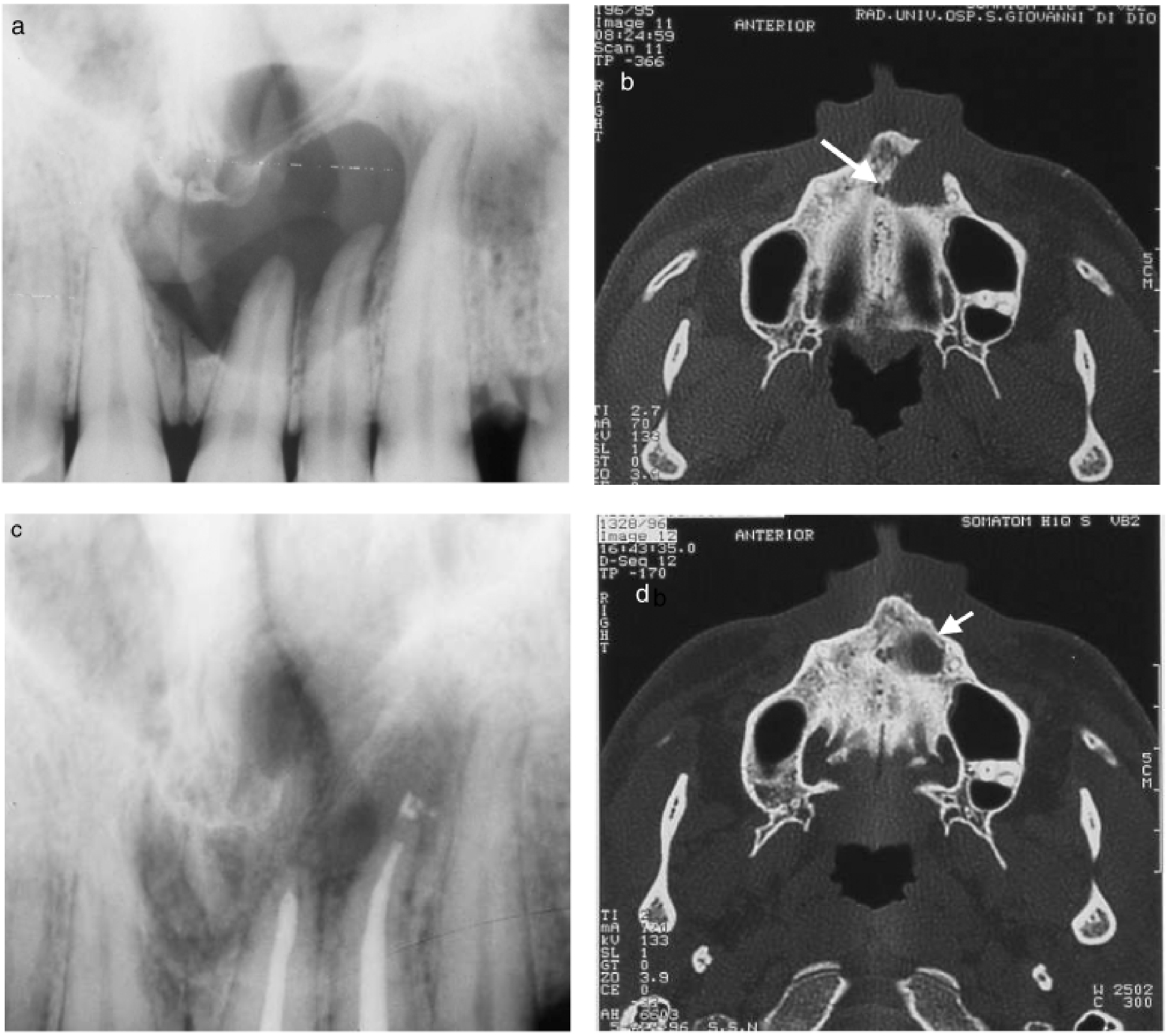

Fig. 6. Lesion of endodontic origin in the periapical areas of the upper left front teeth. (a) Periradicular lesion as seen in the panoramic radiograph. (b) The same lesion as seen in the axial slice of the computerized tomography (CT). The major diameters of the lesion and the erosion of the external cortical plate and the involvement of the incisal canal (arrow) are shown. (c) Healing of the same lesion as seen in the panoramic radiograph 18 months after endodontic treatment. Healing appears close to be completed. (d) CT axial slice of the lesion at the 18 months follow-up. The CT shows that the external cortical plate has been repaired (arrow), but the lesion in the bone is still large.

Fig. 5. Lesions of endodontic origin in the periapical area of upper left canine. (a) Periapical lesion on upper left canine. In the periapical radiograph, it is not possible to visualize the extension of the lesion. (b) Periapical lesion of the same tooth as shown in an axial slice on computerized tomography (CT) (arrow). The root of the tooth is visible, the extension of the lesion in its major diameters and the external cortical plate perforation are evident. (c) More cranial axial slices from CT of the same lesion. The extension of the lesion and the involvement of the floor of the nose are clearly shown.

It has a preference for the posterior body and ramus of the mandible. Radiographically this lesion has a varied appearance: a well-defined radiolucent lesion; a radiolucent lesion associated with a tooth (not distinguishable from a dentigerous cyst), or an expansive multilocular or unilocular lesion (similar to the ameloblastoma). As a consequence of all these forms, the keratocysts should always be considered in the differential diagnosis of the cystic lesions in the jaws, and this is important also because this lesion has a

Fig. 7. **Endodontic lesion in the periapical area of the upper right canine. The tooth had a history of trauma, a short root with open apex, and was refractory to apexification treatment with calcium hydroxide. (a) The upper right canine in the periapical radiographs. The short root, the open apex and the periradicular lesion are seen. (b) One-year follow-up periapical radiograph after apexification treatment was started; the lesion is unaffected and there is no evidence of apical hard tissue barrier formation or periapical healing. (c) Computerized tomography examination of the lesion. The apex of the tooth, the erosion of the external cortical plate and a small calcified particle (arrow) are shown. (d) After endodontic surgery was performed, the calcified particle turned out to be a small root fragment. It was removed and the lesion was curetted. The 1-year follow-up radiograph shows healing of the periapical tissues and formation of an apical barrier.**

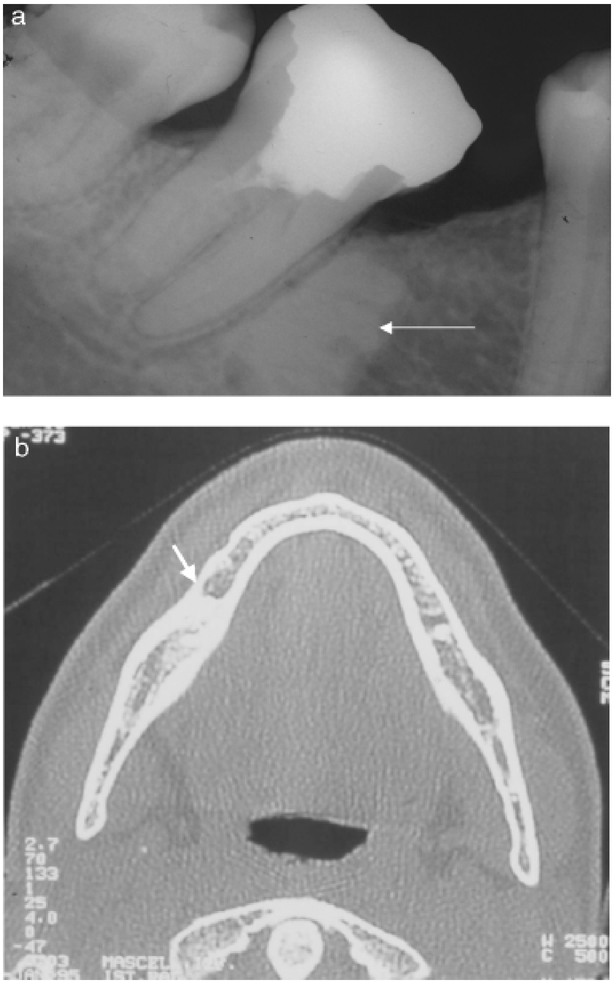

Fig. 8. Radiopaque bone lesion in the mesial periradicular area of the lower left second molar. (a) Periapical radiograph showing the lower left second molar and an area of radiopacity mesial to his mesial root (arrow). (b) Computerized tomography axial scan of the same area showing that the lesion is an enostosis with a central area of bone sclerosis.

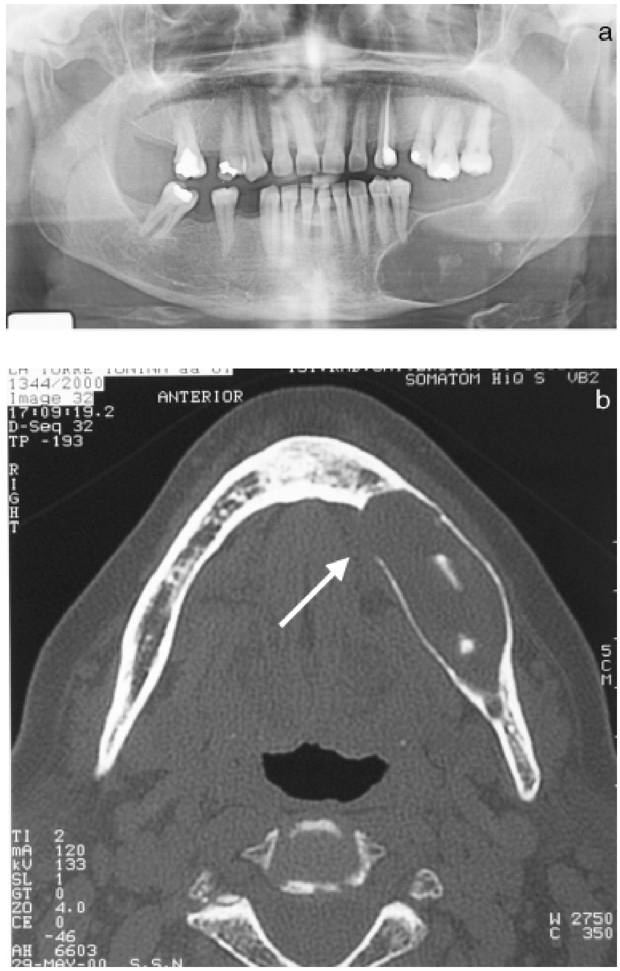

Fig. 9. Keratocyst of the mandible. (a) Panoramic radiograph showing the lesion in the left mandible. (b) Axial slice of the cyst showing the development of the lesion, which is mostly parallel to the long axis of the mandible. There is a visible expansion of the cortical plates and the lingual is eroded (this is a frequent occurrence with this kind of lesions).

recurrence rate of 13–60% after surgical treatment (Fig. 9a, b).

The dentigerous cyst is a common cyst of the jaws and is located around the crown of an unerupted tooth as a result of the cystic degeneration of the enamel organ. This lesion also is more often located in the mandible in the third molar area. The differential diagnosis of a dentigerous cyst is usually less complicated because of the association of this lesion with the crown of the tooth (24) (Fig. 10a, b).

In a study that compared the morphology of these three lesions (radicular cyst, keratocysts, dentigerous cyst) based on CT scans (25), it was observed that the odontogenic keratocysts and the dentigerous cyst tend to develop more in a direction parallel to the long axis of the mandible rather than perpendicular to it; the keratocysts tend to show a discontinuity in the lingual cortex more often than the radicular cyst. They can exhibit unilocular or multilocular patterns, but the dentigerous cyst is almost always unilocular and may present with a local expansion of the cortical plate. The radicular cyst is mostly unilocular, shows discontinuity of the cortex towards the lingual surface of the mandible less often, has an overall rounder shape, and is often surrounded by a sclerotic bone rim (Figs 4 and 6).

The nasopalatine canal cyst and the static bone cyst, also called Stafne's cyst, are developmental, non-

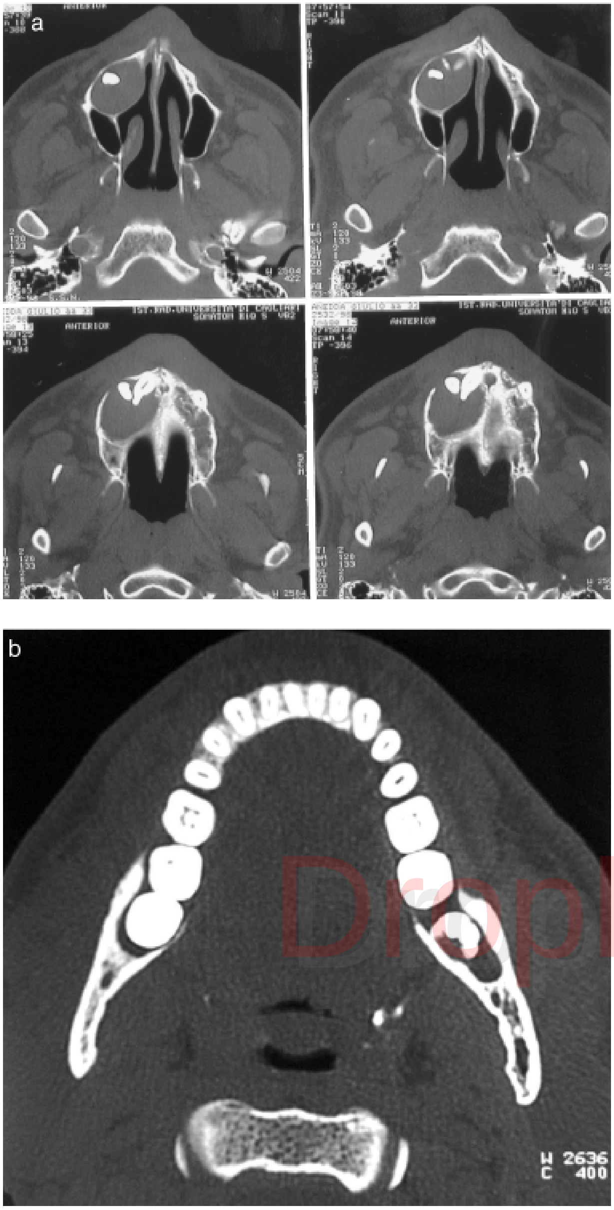

Fig. 10. Computerized tomography (CT) examination of a dentigerous cyst of the left maxilla and of the right mandible. (a) Axial CT image of the maxillary bone demonstrating an extensive dentigerous cyst.The external cortical plate has been invaded; the impacted teeth are within the cyst (arrow). (b) Axial CT of the mandible showing a dentigerous cyst, the crown of the impacted tooth and its extension parallel to the major axis of the mandible.

odontogenic cysts (24). The nasopalatine canal cyst occasionally forms from proliferation of the epithelial or mucous cells of remnants of the nasopalatine canal and is usually asymptomatic. On panoramic radiographs it appears as an oval or heart-shaped radiolucent lesion located between the roots of maxillary central incisors. Sometimes it may be difficult to trace the lamina dura of these teeth, thus rendering the differentiation of the lesion from apical periodontitis difficult. On CT it appears as an enlargement of the nasopalatine canal on axial or coronal sections through the anterior maxilla. Multiplanar and 3D imaging may be important to demonstrate the extent of this lesion (24).

The static bone cyst (24, 26) is a depression in the lingual surface of the mandible; it results from aberrant tissue of the submandibular gland. Usually located below the level of the mandibular canal in the area between the first molar and the angle, it may occasionally be found in the anterior mandible, making the diagnosis more challenging. Dental CT is considered the most suitable non-invasive diagnostic modality for this bony radiolucency: it shows a well-corticated defect in the lingual aspect of the mandible and the associated glandular tissue (26).

The traumatic bone cyst is a cavity that may occur in the posterior mandible. It is not lined by epithelium and is therefore considered a pseudocyst. The causes of its development are not clear; but it is supposed to be the consequence of an intramedullary haematoma following trauma (24, 27). A lesion that is detected early may contain blood or serosanguinous liquid, later it may appear as an empty cavity. Radiographically, it is a well-defined radiolucent area, which may extend between the roots of the teeth without causing interruption of the lamina dura. On the axial CT scans it typically show expansion with thinning and scalloping of the cortical plate and its possible fluid content.

The ameloblastoma represents approximately 1% of the tumours of the jaws. It may be locally invasive and may degenerate into malignancy. It is more often found in the mandible (ascending ramus and molar region) and derives from epithelial cells either from the dental lamina or from an odontogenic cyst. Radiographically, it shows a well-circumscribed multilocular or unilocular radiolucent area, which may be associated with resorption or displacement of the roots of the teeth involved. The differential diagnosis with periapical lesions is more complex when the lesion is unilocular. The CT shows the expansion of the bone and is very important in following up the lesion at regular intervals (24, 25) (Fig. 11a, b).

The giant cell granuloma is another lesion that occurs more often in the mandible (anterior) and has the radiographic appearance of an irregular radiolucent area that may be unilocular or multilocular and tend to

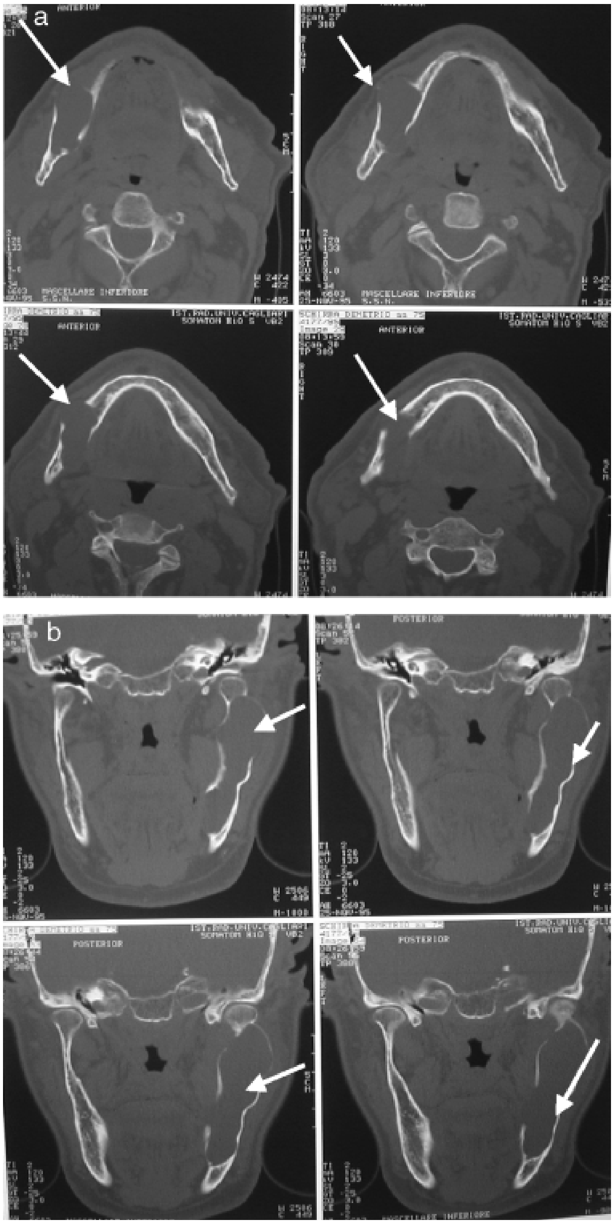

Fig. 11. Computerized tomography (CT) examination of an ameloblastoma of the mandible. (a) Axial CT image of the right ramus demonstrating an extensive unilocular ameloblastoma involving the mandible. Both cortical plates have been invaded. (b) Axial CT of the same ameloblastoma showing its vertical extension and the invasion of the cortical plates and soft tissues.

resorb the roots of adjacent teeth. Small lesions may simulate the apical periodontitis. In CT scans they are distinguishable because they are non-corticated (24).

Periapical cemental dysplasia is considered one of the possible manifestations of cemento-osseous dysplastic/reactive lesions of the jaws and is predominantly located in the mandible. The initial phase is always radiolucent, and at this stage the distinction from periapical lesions may be difficult. A second stage shows a complex radiographic appearance with a progressive development of coalescent radiopacities; in the final stage the lesion is predominantly radiopaque. Axial CT scans are useful to identify, describe and discriminate these lesions: they show radiopaque masses surrounded by low-density areas with no continuity with the cortical plate (as in enostosis) and no continuity with the root of the teeth (like in the cementoblastoma). In this kind of lesions, the CT number of the pixels in the region of interest (expressed in HU) of the high-density masses is important to differentiate cemental lesions from odontomas. The CT number for low-density masses is influential in differentiating cemental dysplasia from keratocysts. It is also important to distinguish cemental dysplasia from fibrous dysplasia, which is a generalized dysplastic condition (24, 28) (Fig. 12a–d).

Alternative CT techniques

Because the CT instruments in use are usually large devices, located in hospital facilities, expensive and non-specific for dental applications, and with high radiation doses involved in their use, different, alternative 3D imaging systems have been developed.

Ortho CT has been described as a compact CT apparatus in which cone beam geometry is used to image the maxillofacial area with high resolution. Data are collected using a dental panoramic machine. In this system, the entrance radiation dose is several dozen times lower than that of conventional CT. Because of its reduced field size, it is not possible to examine lesions exceeding 30 mm without repeated scanning. Another drawback is the inability of this technique to discriminate soft tissues because of its low contrast resolution (29).

Tomosynthesis is an analogue of CT that uses a number of conventional radiographic images on films to extract a slice through the region of interest, by overlapping the images and eliminating the unwanted parts of the object. TACT is a more specific digital version of tomosynthesis. It uses a fiducial mark for the registration of the images and requires a conventional radiographic apparatus, a digitising system and specific software (30). It has been shown to visualize root canals better than conventional radiographs (31), and is suitable for evaluation of crestal defects in the jaws (32).

Local CT is an imaging geometry in which a beam just wide enough to cover only the area of interest is

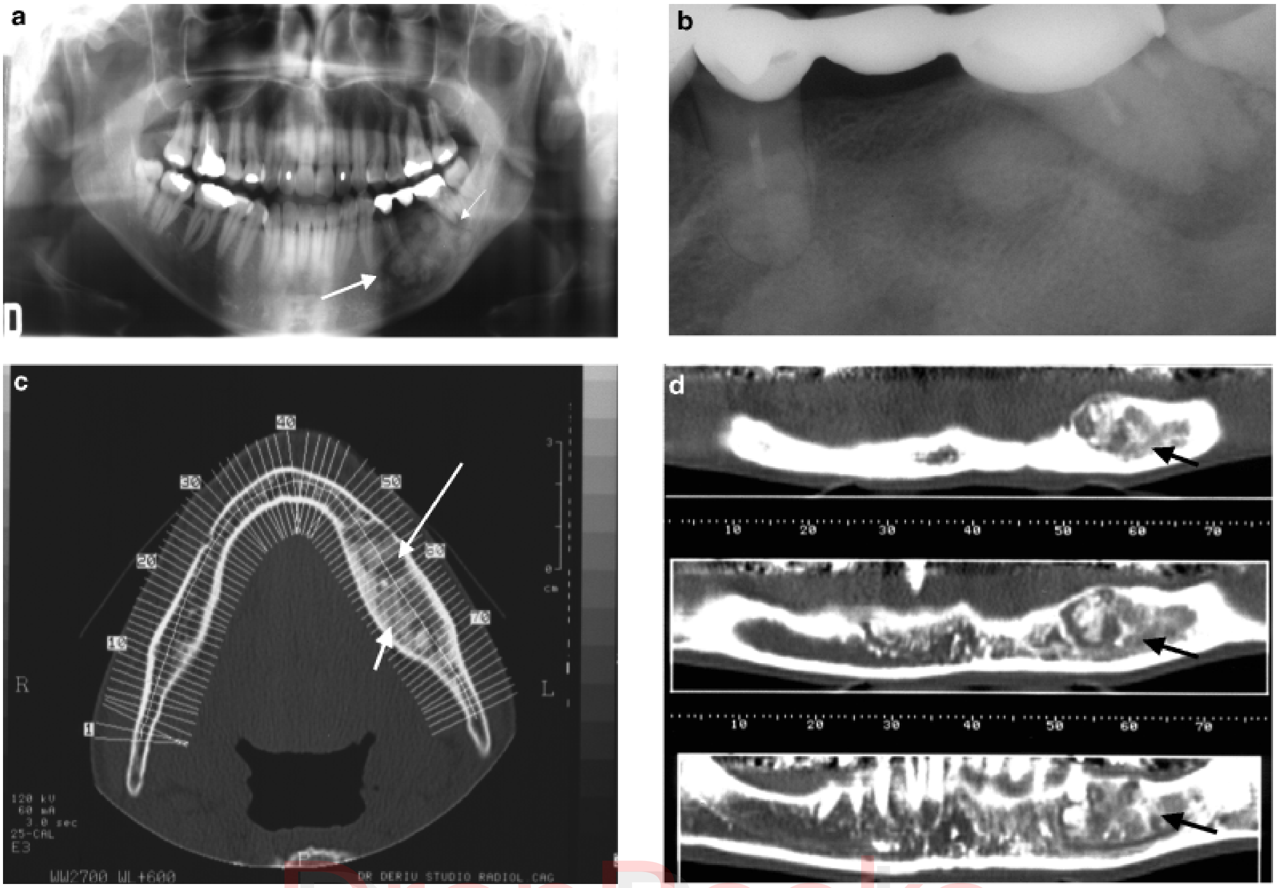

Fig. 12. Computerized tomography (CT) examination of a fibrous dysplasia of the mandible. (a) Panoramic image of the mandible, demonstrating an extensive dysplastic area (long arrow); within this area a periapical lesion originating from the lower left second molar is shown (short arrow). (b) Intraoral radiograph showing the same lesion in a restricted view. (c) Axial CT section demonstrating the increased bucco-lingual width as well as the areas of radiopacity (short arrow) and radiolucency (long arrow). (d) Three panoramic slices reconstructed along the planning line; they show the different areas of radiolucency and sclerosis within the bone pattern (arrows).

used. This is done in order to reduce the radiation dose to the patient.

In an experimental set-up with a single molar and a dry mandible, it has been shown that local CT reconstructions give a quality of image comparable to that of a CT using wide beam geometry. The resolution of the image was diagnostically adequate (33). Micro CT uses stacked fan-beam geometry and produces 3D reconstruction of the objects examined. Such a desktop micro-CT has been used to reconstruct root canals without requiring a previous disassembly of the teeth (34). In recent evaluations on induced periapical lesions in mice, micro-CT, performed with 150 microtomographic slices of 17 μm increments, gave 3-D morphometrical data on the study of periapical lesions that compared well with the histology (35). The authors found that the widest area of the destructive pattern of induced periapical lesions appeared right under the apical foramen, and that the resorptive lesions were not uniform in nature. They also noticed that the 2-D measurement of area of the periradicular lesions and the 3-D measurement of their volume were highly correlated. Currently, the use of micro-CT may be limited to *in vitro* measurements of small samples due to the high radiation dose required. Experimental systems with reduced dose are being tested.

Magnetic resonance imaging (MRI)

Nuclear magnetic resonance, also called MRI, has been available as an imaging technique since 1984.

MRI combines the use of a magnetic field and some radio frequency antennas called coils. During the MRI

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b

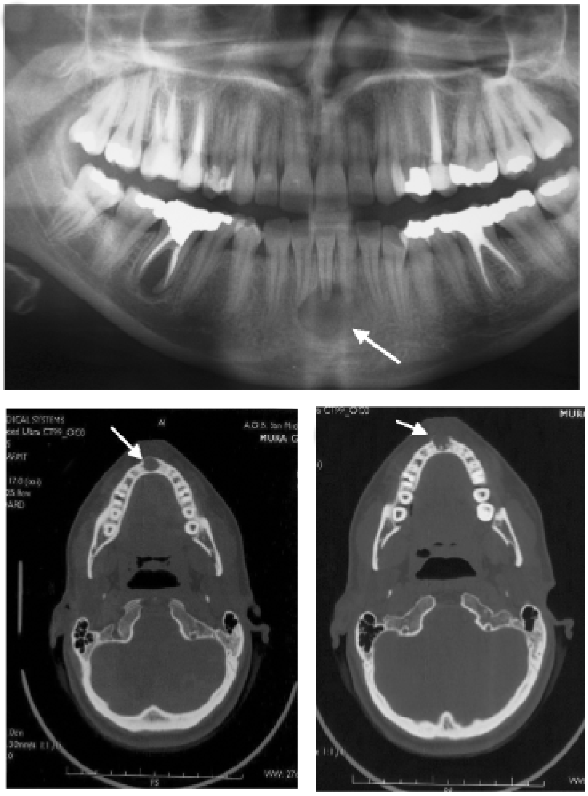


Fig. 13. Lesion in the mandible as shown in panoramic radiograph and computerized tomography examination. (a) Panoramic radiograph showing a round radiolucent lesion in the central mandible (arrow). (b) Axial slices through the mandible. The lesion has caused expansion and erosion of the external cortical plate (arrows).

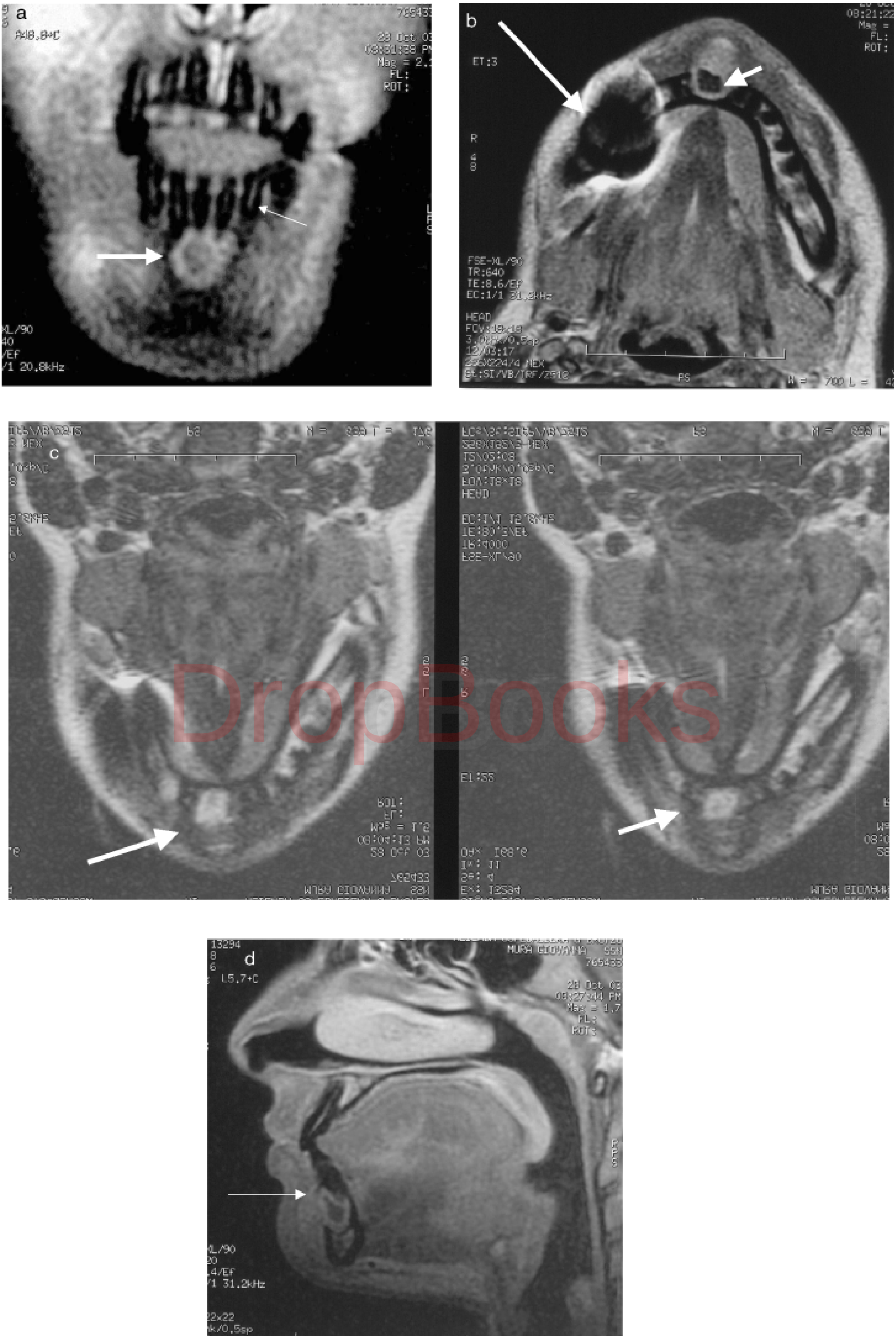
exam a magnetic field is created: this causes the protons in the atoms of water, within the tissues to be examined, to line up. Then pulses of radio waves are sent from a scanner towards the tissue. A high-frequency pulse moves many of the protons out of alignment. As the nuclei realign back into proper position, they send out the radio signals (resonance) that are captured by a radio antenna. The signals are received and measured from a computer system that analyses and converts them into an image of the part of the body being explored. Different atoms in the body absorb radio waves at different frequencies under the influence of the magnetic field. The way in which absorption takes place is measured and used by the computer to construct the images.

Magnetic resonance is a completely non-invasive technique since it uses radio waves; it also allows acquisition of direct views of the body in almost all orientations. Its best performance is in showing soft tissues and vessels whereas it does not provide great details of the bony structures. The strength of the MRI system magnetic field is measured in metric units called Tesla. In MRI bright means high signal intensity, dark means low signal intensity, with all the intermediate shades, i.e.: dense bone = dark, air = ‴ dark, fat = bright. Using a special program, STIR (short tau inversion recovery, fat annulling sequences), water and blood will appear bright. The pictures of MRI will look, as in CT, like sections or cuts. Disadvantages of MRI are a longer scanning time compared to CT, and a strong magnetic field generated, which is why it cannot be used in patients carrying a pacemaker or metal pieces in the areas to be investigated. It is an expensive examination and in most of the systems the patient must be placed in a narrow tube (36–39).

Application of MRI to endodontics

Application of MRI to the dental field started in the late nineties. Studies have been reported on the temporomandibular joints (36), on the assessment of the jawbones prior to implant surgery (37), and on the differential diagnosis of ameloblastoma and odontogenic keratocysts (38).

Gahleitner and his group were the first to apply MRI to the study of the jaws and teeth (39). They evaluated 38 patients, seven of whom were healthy, the others presenting with different dentally related conditions (pulpitis, transplanted teeth, dentigerous cysts) They showed that MRI gives good imaging of the jaw bones, including teeth, pulp spaces and periapical tissues. Pulps were better visualized after administration of a contrast medium. Edema in the periapical region was detectable. Recently a very comprehensive review on MRI and its relationship with the teeth and periapical tissues has been published (40). An open MRI system was used to examine the dental and periapical status in normal patients and in patients who had been diagnosed with periapical pathosis. Slices of 3 mm were undertaken in the transverse, coronal, and oblique sagittal planes using T1-weighted spin echo, STIR fat annulling sequences, and fast low angle shot. In MRI enamel and dentine appear black, the pulp chamber and canal either white or light gray, root fillings are dark. The cortical bone is a black area outlined by lighter, soft external tissues and internal fatty marrow. On STIR (fat


a
b
c
d

annulled scans), fatty marrow has a low signal and appears dark gray. Periapical lesions are clearly seen in the images both on coronal and transverse sections. Any interruption of the cortical plates is also easily seen. Areas of bone sclerosis, which usually surround the periapical lesion, are seen as very low signals (black). On fast low angle shots T1, they are seen as moderate signals (gray) as opposed to the fatty medullary marrow, which gives a strong white signal. This appearance is probably due to the replacement of bone marrow by inflammatory exudates. The same periapical lesions on STIR, on the contrary, are visualized as low-gray to bright white areas: indicating that the area has a high water content and may be oedematous in nature. The altered areas visualized on MRI are considerably more extensive than the same areas when they are observed in orthopantograms or intra-oral radiographs. If the signal is low on T1 and high on STIR, it may be deduced that the lesion is cystic in nature. If the signal is mixed on both, then the lesion is more likely to be a chronic mixed infection (granuloma-infected cyst).

From these studies, it may be concluded that MRI can be used for investigation of pulp and periapical conditions, the extent of the pathosis and the anatomic implications in cases of surgical decision-making (Figs 13a–c and 14a–d).

When an infective lesion like a periapical abscess is expanding fast in the jawbones and in corresponding soft tissues, degenerating into osteomyelitis, MRI becomes an elective diagnostic technique (24).

Fig. 14. Lesion of Fig. 13, as shown in magnetic resonance imaging (MRI) examination. (a) Coronal slice in MRI showing a well circumscribed solid lesion in the central mandible. The lesion is visible (big arrow). The pulp chamber of the teeth is visible in this image (small arrow). (b) MRI, axial slice through the mandible; the lesion extends through the external cortical plate and through the soft tissues (small arrow). On the left side of the image, the dark area is an artefact due to the metallic restoration of the tooth (big arrow). (c) MRI, axial slices in T1 fat sat sequences; the lesion and its relationship with the soft tissues is very clearly showed (arrows). (d) MRI, lateral slice showing the same lesion (arrow). On the MRI sequences, the solid nature of the lesion, its involvement of the soft tissues, its blood content, are easily detected. The MRI diagnosis was of a granulomatous lesion.

Ultrasound real-time imaging

Real-time ultrasound imaging, also called real-time echotomography or echography has been widely used diagnostic technique in many fields of medicine. The imaging system in echographic examination is based on the reflection of ultrasound waves (US) called 'echos'. The US oscillating at the same frequency are generated, as a result of the piezoelectric effect, by a synthetic crystal and are directed towards the area of interest via an ultrasonic probe. The different biological tissues of the body possess different mechanical and acoustic properties. When the US encounter the interface between two tissues with different acoustic properties, they undergo the phenomena of reflection and refraction. The echo is the part of the US that is reflected back to the crystal. The intensity of the echos depends on the difference in acoustic properties between two adjacent tissue compartments: the greater the difference, the greater the amount of reflected ultrasound energy, and the higher the echo intensity. Echos are then transformed into electrical energy and into light signals in a computer inside the machine. The movement of the ultrasonic probe produces the US images seen on the monitor over the part of interest in the body. Since each movement gives one image of the tissue and there are an average of 30 images per second, the exam will appear in the monitor as moving images. The interpretation of the gray values of the images is based on the comparison with those of normal tissues. The color power Doppler is based on the red blood cell's Rayleigh's scattering effect and on the Doppler effect. When applied to the echographic examination, it allows representing the presence and direction of the blood flow (Doppler), under the format of color spots superimposed to the images of blood vessels (color), and the intensity of the Doppler signal with its modifications in real time (power) (40, 41).

The intravenous injections of substances (contrast mediums) will increase the echogenicity of the blood and will render the echo-power-Doppler exam more sensible by creating a major difference of acoustic impedance in the area of interest (41). Ultrasound imaging is considered to be a safe technique, but the energy of US waves is absorbed in the form of heat from the biologic tissues that need to be controlled. This potentially adverse effect of the system depends on the time of application of the sound energy; therefore, one

seeks to limit the number and the repetitions of the exams (42–44). In any case the risk is much lower than the risk associated with radiographic investigations (40–44).

Ultrasound imaging in endodontics

The application of echographic examination to the study of endodontic disease has been attempted with success (45). The technique is easy to perform and may show the presence, exact size, shape, content and vascular supply of endodontic lesions in the bone. The echographic probe, covered with a latex protection and topped with the echographic gel, should be moved in the buccal area of the mandible or the maxilla, corresponding to the root of the tooth of interest. The regular probe, so far, has been performing well even if a more specific instrument for dental use should be made available. Alveolar bone appears as a total reflecting surface (white) if healthy; the contours of the roots of the teeth are even whiter (Fig. 15a) this tissue is then considered hyperechoic. A fluid-filled cavity in the bone appears as a hypo-reflecting surface (dark) to different degrees, depending of the cleanliness of the fluid (hypoechoic): a simple serous filled cavity has no reflection (anechoic or transonic) (Fig. 15b). Solid lesions in the bone have a 'mixed echogenic appearance', which means their echos are reflected with various intensities (light grayish) (Fig. 15c). If the bone is irregular or resorbed in proximity of the lesion, this can be seen as an inhomogeneous echo; if the bony contour limiting a lesion is reinforced, then it is very bright. Major anatomic landmarks, such as the mandibular canal, mental canal, and maxillary sinus, are clearly distinguished and mostly transonic. At the color power Doppler, the vascularization within the lesion and around it can be seen; the details of it are enhanced by the use of contrast mediums. A differential diagnosis between cystic lesions and granulomas may be done based on the following principles (46): cystic lesion: a transonic, well-defined cavity filled with fluids and with no evidence of internal vascularization at the color power Doppler (Fig. 16a, b); granuloma: a distinct lesion showing not well-defined contours, which can be

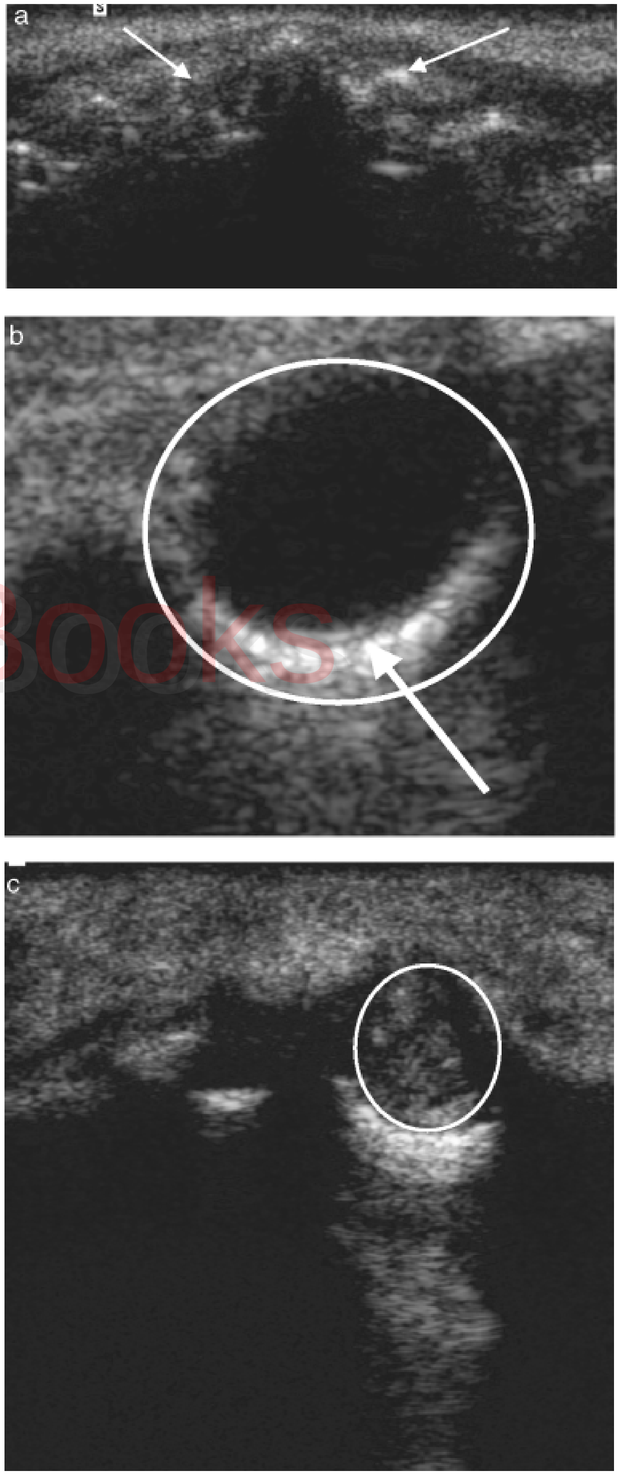


Fig. 15. Ultrasound real-time imaging of the jaws. (a) Echographic view of the profile of the mandible: the contours of the roots are visible (arrows); the image represents a 'hyperechoic' area where total reflection occurs. (b) Cystic lesion as seen in the ultrasound image (circled): it is an 'anechoic' or 'transonic' cavity where no reflection occurs: the reinforced bony contour of this lesion is 'hyperechoic' (arrow). (c) Periapical lesion as seen in the ultrasound image (circled). It is an 'echogenic' area where echoes are reflected back at different intensities.

Fig. 16. Ultrasound real-time imaging of a periapical lesion of the maxillary bone. (a) Periapical lesion as seen in the intraoral periapical radiograph; the lesion involves the periapical area of the upper left front teeth. In this image, it is not possible to visualize the extension of the lesion in the bone. (b) The same lesion as seen in the ultrasound image (circled): it is a 'transonic' cavity with reinforced hyperechoic bony contour (arrow); it shows a fluid content. The major diameter is indicated by the dotted line. The echographic diagnosis was of 'cystic lesion'; the histopathologic report confirmed it.

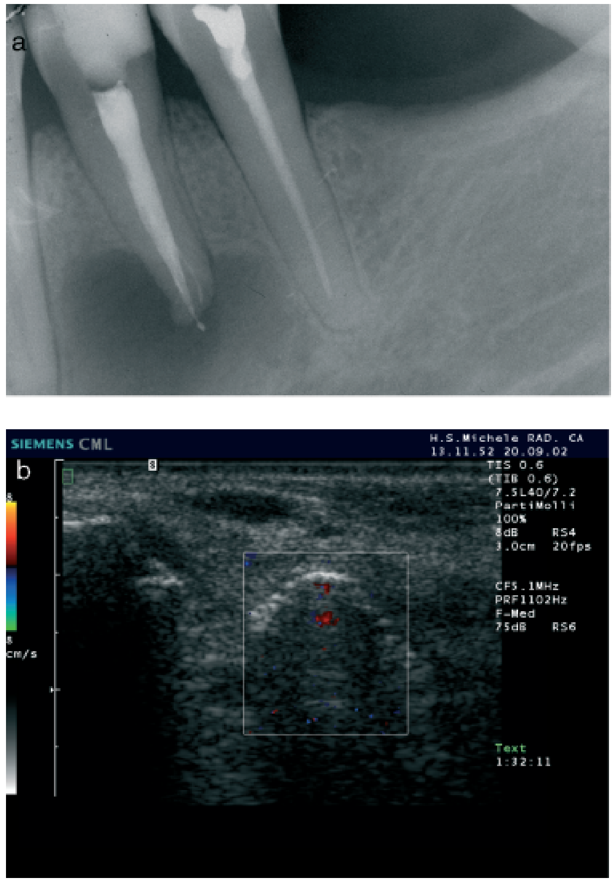


Fig. 17. Ultrasound real-time imaging of a lesion of endodontic origin in the mandible. (a) Periapical lesion corresponding to the periradicular area of the lower left first bicuspid, as seen in the radiograph. (b) The same lesion as seen in the ultrasound image (framed): it is an 'echogenic' area showing the presence of vascular supply at the color power doppler (blue and red spots); it was diagnosed as a periapical granuloma and the diagnosis was confirmed by the histopathologic report.

frankly corpusculated (echogenic), or may show both corpusculated and hypoechoic areas (Fig. 17a, b), exhibiting a vascular supply at the color power Doppler with or without contrast medium (Fig. 18). The sensitivity of the technique makes possible a distinction between serous and inflammatory exudates in cysts. However, at its current stage of development, the echographic examination may not help in distinguishing between other kind of cystic conditions (i.e. keratocysts, traumatic bone cyst, developmental cyst) as the cavity is well visualized and its contents, be it fluid or particulate, can hardly be distinguished (Fig. 18a, b). Fibrous tissue within a lesion maybe distinguished with more details; also calcified particles can be observed.

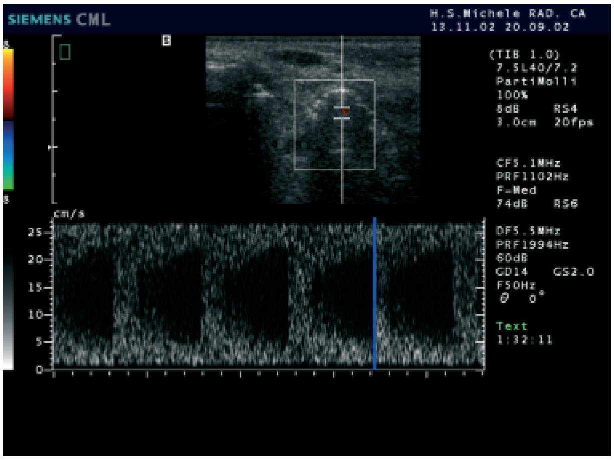


Fig. 18. Picture representing the echo color power Doppler applied to the echographic examination of the previous case. In the upper portion of the picture, the echographic image is visualized (ehco), together with the colored spots representing the presence and direction of the blood flow (color-Doppler). In the lower part the intensity of the Doppler signal with its time modification is pictured (power).

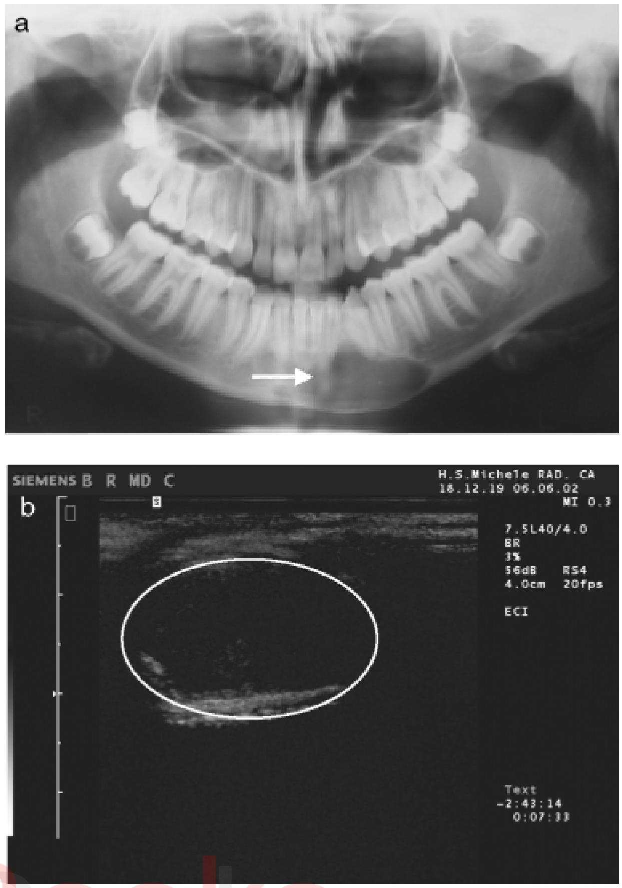


Fig. 19. Echographic examination of a traumatic bone cyst of the mandible. (a) Panoramic radiograph showing the wide radiolucent lesion in the anterior mandible. (b) Ultrasound imaging of the same area: it appears as a cystic lesion; the lesion diagnosed as a traumatic bone cyst with sero-sanguinous content.

Conclusions

The possibility to monitor biological changes in the diseased bone in the field of periapical disease is always challenging. From time to time it may be important to be able to see a lesion in its real extension, to evaluate its content, to assess its precise relationship to anatomic landmarks such as the mandibular canal, mental foramen, incisal foramen, floor of the maxillary sinus, etc., and to speculate on its expansion, vascularization, pattern of bone destruction, and evolution in time. When it comes to the most common needs for differential diagnosis of lesions of the jaws, the issue is even more urgent. Many relatively new 'special imaging techniques' are available today that may reach these goals. Some are well established, others are currently being tested with promising results. It is necessary to stress that most of the alternative imaging techniques may be very expensive, or less safe for the patient because of high radiation doses. Others may be extremely sensitive but difficult to interpret. They should therefore be used with the proper indication, and performed by well-trained professionals.

Dental CT is now universally considered a useful complement to conventional radiology techniques. In endodontics, it may be useful for identification of large lesions and their relationship to anatomic structures prior to endodontic surgery as well as for evaluation of the pattern and the content of the lesions when there may be a diagnostic challenge (different kind of cysts, unilocular ameloblastoma, dysplastic forms and suspected tumours). Furthermore, CT must be prescribed with the specific indication of the area of interest and possibly the number of scans required. It should not be repeated if not strictly necessary. Alternative CT techniques are promising, but still under evaluation; therefore, they cannot be adopted for routine use so far. Local CT appears particularly promising. Micro-CT is still confined to the field of research, especially in correlation with clinical and histopathological investigations, which is important for the knowledge of the characteristics and mechanisms of these pathologic conditions. MRI, as stated before, is extremely expensive; it should be left to differential diagnostic

problems that mostly involve abnormal spreading of lesions in the bones, evaluation of lesion content, involvement of soft tissues, nerves and vascular supply. Ultrasound imaging seems to be a better compromise in that is not as expensive as CT and MRI or dangerous in terms of radiation risk as CT. If conducted with a limited number of examinations it does not entail biologic adverse effects. Clinically it may be useful for dimensional assessment of the pathologic areas and for the specific evaluation of fluid versus solid content of the lesions. There is a definite future in the study of the blood flow and the way it relates to the pathogenesis and expansion of the bony defects. Ultrasound has potential in the differential diagnosis of cysts versus granulomas; cystic content may be defined as 'clean' or 'particulate'. The technique may certainly be used in research on periapical pathology. Its major drawback, besides the fact that echographic machines are not so commonly found, is that image interpretation is quite difficult and requires extensive operator training and experience.

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